NACE Cathodic Protection Technologist Level 3 Case-Based Exam

Exam Preparation Guide

September 2020

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Introduction

The Cathodic Protection Technologist Case-Based exam is designed to assess whether a candidate has the requisite knowledge and skills that a minimally qualified Cathodic Protection Technologist (CP 3) must possess. The exam consists of 30 multiple-choice, multiple-choice with more than one correct answer, and matching questions related to a case, scenario, or problem that requires the application of knowledge based on the CP body of knowledge. A candidate should have theoretical concepts and practical application of CP with a strong focus on CP field work, interpretation of CP data, and troubleshooting.

Exam Name	NACE-Cathodic Protection Technologist Case-Based Exam
Exam Code	NACE-CP3-Case-Based
Time	4 hours*
Number of Questions	30
Format	Computer Based Testing–CBT

NOTE: *A pass/fail grade is provided at the end of the exam. The Theory and Case-Based exams are scored separately, and candidates must pass both exams.*

*Exam time includes 4 minutes for the non-disclosure agreement and 6 minutes for the system tutorial.

NOTE: *The CP 3 course manual is **NOT** provided in the exam. Reference material is provided as a PDF for questions that require an equation, conversion chart, or other reference.*

Target Audience

A Cathodic Protection Technologist (CP 3) is responsible for observing, recording, and measuring the effectiveness of CP systems. This certification is geared toward persons who have a high level of working knowledge of CP systems and years of extensive field experience in CP. A CP Technologist should have good understanding of mathematical procedures and scientific knowledge of corrosion processes.

NOTE: There is NOT a direct progression from Cathodic Protection Technician (CP 2) to Cathodic Protection Technologist (CP 3). Substantial experience involving all aspects of CP, including design and formal education in math/science/engineering is critical to a candidate's success on this exam. Attendance in the Cathodic Protection Technician (CP 2) course is strongly recommended before attempting Cathodic Protection Technologist (CP 3). However, additional experience and education are also recommended.

Requirements

Cathodic Protection Technologist (CP3)

Requirements for Cathodic Protection Technologist (CP3):
1 Prerequisite + Work Experience + 2 Core Exams + Application

The following prerequisite is required:
None
Work Experience Requirements:
Choose one of the following work experience options:
8 years verifiable CP work experience
6 years verifiable CP work experience **AND** 2 years post high school training from approved math / science or technical / trade school
3 years verifiable CP work experience **AND** 4-year physical science or engineering degree
Core Exam Requirements:
The following exams are required: (2 core exams required)
Cathodic Protection Level 3 Exam (Theory) Cathodic Protection Level 3 Exam (Case-Based)
Application Requirement:
Approved Cathodic Protection Technologist (CP3) application

Submit Application – candidates must apply for this certification by submitting an on-line application which is subject to approval. Applications must be submitted within 3 years of successful completion of exam.

Upon successful completion of requirements, the candidate will be awarded a **Cathodic Protection Technologist Certification.**

Next Level of Certification:
Cathodic Protection Specialist (CP 4)

Exam Blueprint

Instruments

- o Understand the operation of a digital Volt-Ohm meter (Multimeter) and how it is used to measure current, voltage and resistance.
- o Use a volt-ohm meter (Multimeter) to determine the voltage and current output of a rectifier.
- o Understand the operation of a soil resistivity meter.
- o Use a volt-ohm meter to determine the current output of sacrificial anodes installed on your system.
- o Conduct a soil resistivity test with a soil resistivity meter or equivalent instrument.
- o Conduct soil resistivity measurements by using a Soil Box.
- o Understand and able to perform layer resistivity calculations.
- o Conduct single-point soil resistivity readings with a "Collins Rod."
- o Install interrupters in rectifiers or bonds for the purpose of taking “On” and “Instant off” structure to electrolyte potential readings.
- o Understand the various types of pipe locating instruments and be able to utilize them to locate pipelines or cables in all underground environments.

Shunts

- o Understand how to determine the amount of current flowing through various size shunts by reading the milli-Volt (mV) drop across it with a Volt-Ohm meter and applying the correct conversion factor.
- o Understand how to determine the direction of current flow through a shunt by observing the polarity of the mV reading.
- o Read shunts in rectifiers to determine the output current.
- o Read shunts in bonds with foreign structures.
- o Read shunts for individual anodes associated with deep well ground beds.
- o Utilize an external shunt to determine the output current of a rectifier with a broken amp meter.
- o Read shunts that are installed in galvanic anodes to determine output current

Field Tests

- o Perform current requirement test.
- o Perform soil pH test.
- o Perform IR Drop test.
- o Run "shorted casing test" on casings that are suspected of being shorted and interpret the results of the test.
- o Perform coating examinations on sections of pipeline that have been excavated.
- o Perform soil resistivity test to evaluate the area for a conventional ground bed site.
- o Conduct Pearson surveys to evaluate the coating condition of a section of pipeline.
- o Conduct computerized close interval surveys where needed and evaluate the graphs produced from the data.
- o Locate breaks in header cables with an "audio type" pipe and cable locator.
- o Investigate shorts on a pipeline or other structure.
- o Verify the results of shorted casing test.
- o Understand the factors that affect cathodic protection system performance at the anode, at the structure performance, in the electrolyte, in the metallic path, at the power supply, because of anode arrangement and interference.
- o Perform advanced cathodic protection testing using correct measurement techniques to monitor CP system performance and accurately interpret the data collected to ensure optimum cp system performance.
- o Based on data collected, determine if correction/modifications to system components are necessary.
- o Identify errors in data collection/CP measurements including contact resistance errors, voltage drop errors, and reference electrode errors.
- o Utilize the instruments required to accomplish advanced cathodic protection testing and collection of cathodic protection systems measurements.
- o Conduct cathodic protection surveys including close interval surveys and DCVG where needed or required and evaluate the graphs produced from the data collected during the surveys.
- o Troubleshoot rectifiers and make corrections/repair as necessary.
- o Perform efficiency test on rectifiers.

- Install new rectifiers.
- Understand the use of external CP coupons and be able to identify if the use of external coupons is needed for a CP system.
- Understand in-line and direct inspection (*understand and be able to implement ECDA).*

DC Stray Current Interference

- Conduct and document interference test where stray currents are suspected.
- Once interference tests have been run, suggest method of control that will mitigate the effects of the stray current.
- Understand how IR Drop test stations can be used to evaluate stray current.
- Understand how Coupon Test station can be used to determine the presence of and the mitigation of stray current.
- Calculate the resistance required for to provide the amount of current drain desired at a resistance bond Installation.
- Understand the causes (sources) and the effects of interference.
- Understand the methods available to mitigate interference.

AC Mitigation

- Understand the safety requirements when installing test stations under high voltage power lines.
- Take appropriate steps to mitigate the effects of excessive AC voltage induced on underground structures.

Corrosion Theory

- Understand the composition of a basic galvanic cell and the electrochemical reactions that allow corrosion to occur at the anode rather than the cathode.
- Describe the characteristics of anodic and cathodic reactions.
- Understand and apply the principles of electricity and electrical circuits (series, parallel, and series-parallel circuits) (including the application of Ohm's and Kirchhoff's Laws to electrical circuits.)
- Perform calculations using Ohm's Law and calculations related to series and parallel circuits.
- Understand how corrosion cells are formed on metal objects that are underground or otherwise immersed in an electrolyte.
- Understand Faraday's Law and perform calculations using Faraday's law to determine required anode weight for cathodic protection.

Polarization

- Understand the cause and effect of polarization in a galvanic cell
- Understand activation, concentration and resistance polarization and the mathematical expressions of these concepts.
- Understand the factors that affect polarization (area, temperature, relative movement, ion concentration, oxygen concentration).

Cathodic Protection

- Understand the concept cathodic protection and be knowledgeable of the Components required for both galvanic and impressed current systems.
- Be able to design and install simplistic forms of galvanic and impressed current cathodic protection facilities.
- Understand the relationship between cathodic protection and other methods of corrosion mitigation.
- Understand the factors that affect the amount of current required for a cathodic protection system.
- Understand the NACE criteria for Cathodic Protection and be able to apply the criteria and make adjustments as necessary to CP systems in order to comply with the criteria defined by the company where the technologist is employed.
- Understand IR drop and be able to determine the IR drop and apply correction techniques as needed.
- Understand and apply E Log I criteria and construct polarization curves.
- Understand the concept of current distribution and be able to determine ideal current distribution for a CP system taking into account the factors affecting current distribution (anode-to-cathode separation distance, electrolyte and structure resistivity variation, current attenuation).
- Understand the effects of current path geometry, protective coatings and polarization on current distribution.

Design

- Utilize field data to accomplish the calculations required to design cathodic protection current sources.
- Select site locations and implement the design of cathodic protection current sources for distribution or transmission pipeline systems.
- Design cathodic protection systems for the inside of water tanks.
- Design cathodic protection for the tank bottoms of aboveground storage tanks.
- Design cathodic protection for underground storage tanks
- Work with engineering in the proper use of insulation for newly designed facilities.
- Provide information on underground coating performance for those selecting coatings for new facilities.

Types of Questions

Description of Questions

This closed-book exam consists of multiple-choice questions which may have multiple answers and require selection of more than one answer choice, as well as matching items. The cases require a candidate to apply knowledge and skills to answer the questions based on the problem presented in each case. The questions are based on the knowledge and skills required in the CP industry for a Cathodic Protection Technologist.

Sample Questions

The sample questions are included to illustrate the formats and types of questions that will be on the exam. Your performance on the sample questions should not be viewed as a predictor of your performance on the actual exam.

Problem Statement

The subject pipeline is a 24-inch outside diameter 4,500 linear foot horizontal directional drill under a river. The Pipeline is provided with a mill applied 16 mil thick Fusion Bonded Coating and a 60 mil thick Abrasion Resistant Overcoat. The pipeline girth welds are field coated with a 70 mil thick liquid epoxy coating. CP is to be provided by a local system dedicated to the HDD Pipeline.

Key Assumptions

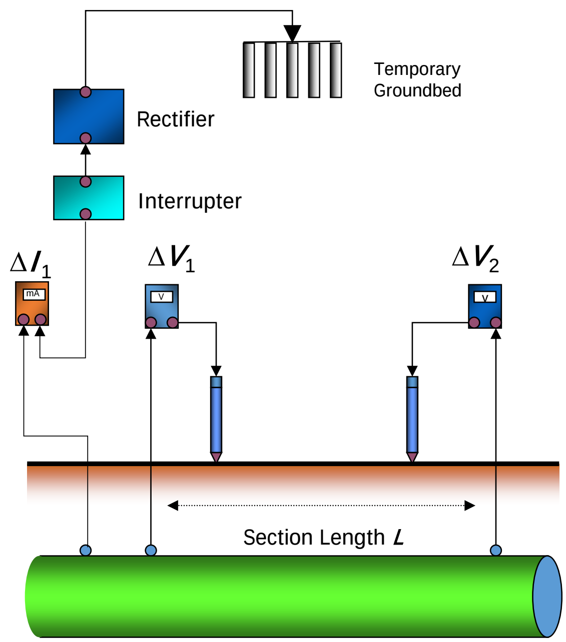
The coating quality and CP current requirement are to be assessed prior to the pipeline being welded to (connected to) the upstream and downstream pipeline segments beyond the limits of the direction drill.

Reference Material

What is Coating Conductance?

- A relative measure of the ability of a coating to conduct (collect) current from the CP System.
- Conductance was originally designated in units called mhos (**ohm** spelled backwards, symbol is ℧).
- Today the International Unit for Conductance is Siemens (S = 1/Ω).

A Typical Test Setup Schematic is shown below:



A coating Quality Comparator is shown in the following Table:

Effective Coating Resistance (ohm-ft²)	Estimate of Coating Quality	Bare Area (%)	Coating Efficiency (%)
Bare	-	100	0
10,000	Poor	3	97
25,000	Fair	1.2	98.8
50,000	Fair	0.6	99.4
100,000	Good	0.3	99.7
500,000	Excellent	0.06	99.94

Applicable Formulas (Would Be Provided)

- *Applied Test Current* $= \boldsymbol{I_T}$
- *Voltage Shift resulting from Applied Test Current* $\Delta\boldsymbol{V}_1$ *and* $\Delta\boldsymbol{V}_2$
- *Resistance-to-Earth of Pipe* $\boldsymbol{R}_P = \Delta\boldsymbol{V}_{AVG} / \Delta\boldsymbol{I}_T$
- *Pipe Coating Resistance* $\boldsymbol{R}_c = \boldsymbol{R}_P \times \boldsymbol{A}$ *where* $\boldsymbol{A} = \boldsymbol{\pi dL}$
- *Pipe Coating Conductance* $\boldsymbol{S}$ *is* $\boldsymbol{1/ R_c}$

Applicable Data

- The Native (Static) Pipe-to-Electrolyte Potentials at Locations V_1 and V_2 are -0.700 Volts/CSE and -0.630 volts/CSE respectively.
- The Applied test current is 0.050 Amperes.
- The Current Applied "On" Pipe-to-Electrolyte Potentials at Location V_1 and V_2 are -1.400 Volts/CSE and -1.300 Volts/CSE respectively.
- The Current "Off" Pipe-to-Electrolyte Potentials at Locations V_1 and V_2 are -0.850 Volts/CSE and -0.780 volts/CSE respectively.

Questions

1. What technique is <u>best</u> used to assess the protective coating quality of the pipeline?
   A. Close Interval Potential survey
   B. Pipe-to-Electrolyte Potential Measurement
   C. Coating Conductance Measurement
   D. Coating Attenuation Survey

2. In the example provided, what is the calculated Pipe-to-Earth Resistance R_P?
   A. 27Ω
   B. 16.3Ω
   C. 13.7Ω
   D. 10.7Ω
   E. 3Ω

3. In the example provided, what is the calculated Pipe Coating Resistance R_C?
   A. 650,000 Ohm-ft^2
   B. 302,535 Ohm-ft^2
   C. 250,364 Ohm-ft^2
   D. 52,298 Ohm-ft^2
   E. 102,000 Ohm-ft^2

4. In the example provided, what is the calculated Pipe Coating Conductance ***S*?**
   A. 1.305 µS
   B. 200 µS
   C. 3.304 µS
   D. 10 x 10^{-6} S
   E. 23 x 10^{-6} S

5. Using the data provided, what is the total current required to achieve a minimum polarized pipe potential of −0.900 $\text{Volts}/_{\text{CSE}}$?
   A. 100 mA
   B. 50 mA
   C. 0.090 Amperes
   D. 0.050 Amperes
   E. 1.500 Amperes

6. Using the information provided, rate the quality of the coating.
   A. Poor
   B. Fair
   C. Good
   D. Excellent
   E. Very Poor

Answer Key

1. C
2. D
3. B
4. C
5. C
6. C

Preparation

Training—None Required

NACE Cathodic Protection Technologist—Course CP 3 (Available)

NACE Cathodic Protection Technician—Course CP 2 (Available)

NACE Cathodic Protection Tester— Course CP 1 (Available)

Recommended Study Material

Books

Peabody, A. W. (2001). *Peabody's control of pipeline corrosion* (No. Ed. 2). NACE international.

NACE Cathodic Protection Technologist—CP 3 course material

Standards

NACE International SP 0207 (2007). "Performing Close Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines." NACE International.

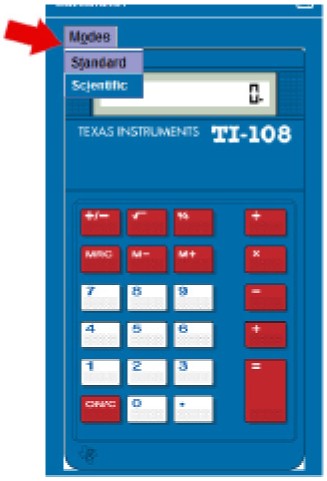
NACE International SP 0169 (2013). "Control of External Corrosion on Underground of Submerged Metallic Piping Systems." NACE International.

NACE International SP 0177 (2014). "Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems." NACE International.

Calculators

Students will have access to either a TI Standard or TI Scientific calculator for use during the CBT Exam.

Standard Calculator



Standard Mode Functions

Add	[+]	
Subtract	[-]	
Multiply	[X]	
Divide	[÷]	
Negative	[(-)]	
Percentage	[%]	
Square Root	[√]	Example: 4 [√]
Reciprocal (Inverse)	X	Example: 1 [÷] 2 [=]
Store value to variable	[M+]	Example: 3 [*] 5 [=] [M+]
Access variable	[MRC]	Example: 7 [+] [MRC] [=]
Clear variable	[M-] [MRC]	

Scientific Calculator

Scientific Mode Functions

Add	[+]	
Subtract	[-]	
Multiply	[X]	
Divide	[÷]	
Negative	[(-)]	
Percentage	[2nd] [%]	
Square Root	[√]	Example: [2nd] [√] 4 [enter]
Reciprocal (Inverse)	[X^{-1}]	Example: 2 [X^{-1}] [enter]
Store value to variable	[sto▶] [X^{yzt}]	Example: 3 [*] 5 [enter] [sto▶] [X^{yzt}] [enter]
Access variable	[X^{yzt}] or [2nd] [recall]	Example: 7 [+] [2nd] [recall] [enter] [enter]

Numeric Notation

Standard (Floating Decimal) Notation (digits to the left and right of decimal	mode menu options **NORM** SCI ENG FLOAT 0 1 2 3 **4** 5 …	 e.g. 123456.78 e.g. 123456.7800
Scientific Notation (1 digit to the left of decimal and appropriate power of 10)	mode menu options NORM **SCI** ENG	 e.g. 1.2345678*105
Engineering Notation (numer from 1 to 999 times 10 to an integer power that is a multiple of 3)	mode menu options NORM **SCI** ENG	 e.g. 123.45678*103

Fractions

Simple fractions	[n/d]
Mixed numbers	[2nd] [Un/d]
Conversion b/w simple fraction and mixed number	[2nd] [n/d ◀ ▶ Un/d]
Conversion b/w fraction and decimal	[2nd] [f ◀ ▶ d]

Powers, roots, and inverses

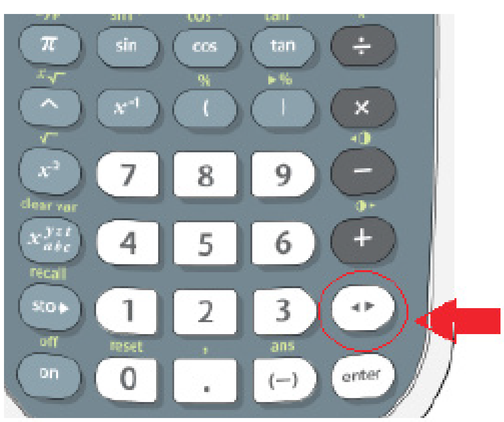
Square a value	[x^2]	
Cube a value	[^]	
Raise value to specified power	[^]	Example (2^4) 2 [^] 4
Square root	[2nd] [√]	Example (√16): [2nd] [√] 16
Reciprocal	[x^{-1}]	Example (n^{th} root): 5^{th} root of 8: 5 [2nd] [^{x}√] 8

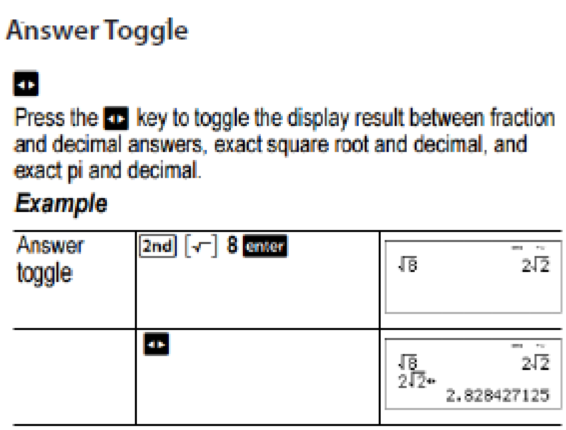
Pi

PI (π)	[π]

Toggle

The scientific calculator might show the results of certain calculations as a fraction - possibly involving pi or a square root. To convert this kind of result to a single number with a decimal point, you will need to use the "toggle answer" button circled in the picture below. Pressing this button will change the display from a fractional to a decimal format.





Answer Toggle

Press the ◀▶ key to toggle the display result between fraction and decimal answers, exact square root and decimal, and exact pi and decimal.

Example

Answer toggle	[2nd] [√] 8 [enter]	√8 2√2
	◀▶	√8 2√2 2√2 2.828427125

Note: If you find this onscreen calculator difficult to use, raise your hand and ask the Test Administrator to provide you with a hand-held calculator. **If available,** you will be provided with a scientific or non-scientific calculator. Candidates are not permitted to bring their own calculator into the testing room.

Reference Material Provided in the Exam

NOTE: All references, including equations, were taken from original sources and may differ from those used in course manuals and presentations

EQUATIONS

RESISTANCE TO EARTH OF SINGLE VERTICAL ANODE

$$R_V = \left[\frac{0.00521\rho}{L}\right]\left[\ln\left[\frac{8L}{d}\right] - 1\right]$$

Where

- R_v = resistance in ohms
- ρ = resistivity in ohm-cm
- L = anode length in feet
- d = anode diameter in feet

OR

$$R_v = \left[\frac{\rho}{2\pi L}\right]\left[\ln\left[\frac{8L}{d}\right] - 1\right]$$

Where

- R_v = resistance in ohms
- ρ = resistivity in ohm-m
- L = anode length in m
- d = anode diameter in m

RESISTANCE TO EARTH OF MULTIPLE VERTICAL ANODES

$$R_v = \left[\frac{0.00521\rho}{NL}\right]\left[\ln\left[\frac{8L}{d}\right] - 1 + \left[\frac{2L}{S}\right]\ln(0.66N)\right]$$

Where

- R_v = resistance in ohms
- ρ = resistivity in ohm-cm
- L = anode length in feet
- N = number of anodes
- S = anode spacing in feet center to center
- d = anode diameter in feet

OR

$$R_v = \left[\frac{\rho}{2\pi NL}\right]\left[\ln\left[\frac{8L}{d}\right] - 1 + \left[\frac{2L}{S}\right]\ln(0.66N)\right]$$

Where

- R_v = resistance in ohms
- ρ = resistivity in ohm-m
- L = anode length in m
- N = number of anodes
- S = anode spacing center-to-center in m
- d = anode diameter in m

NOTE: Use the units specified.

RESISTANCE TO EARTH OF SINGLE HORIZONTAL ANODE

$$R_H = \left[\frac{0.00521\rho}{L}\right]\left[\ln\left[\frac{4L^2+4L\sqrt{S^2+L^2}}{dS}\right]+\frac{S}{L}-\frac{\sqrt{S^2+L^2}}{L}-1\right]$$

Where

- R_H = resistance in ohms
- ρ = resistivity in ohm-cm
- L = anode length in feet
- S = twice the anode depth in feet
- d = anode diameter in feet

OR

$$R_H = \left[\frac{\rho}{2\pi L}\right]\left[\ln\left[\frac{4L^2+4L\sqrt{S^2+L^2}}{dS}\right]+\frac{S}{L}-\frac{\sqrt{S^2+L^2}}{L}-1\right]$$

Where

- R_H = resistance in ohms
- ρ = resistivity in ohm-m
- L = anode length in m
- S = twice the anode depth in m
- d = anode diameter in m

RESISTANCE TO EARTH OF MULTIPLE HORIZONTAL ANODES

$$R_T = \frac{R_H}{N}F$$

Where

- R_T = resistance of multiple horizontal anodes in ohms
- F = Anode Interference or Crowding Factor
- R_H = resistance of single horizontal anode in ohms
- N = number of anodes

ANODE INTERFERENCE BETWEEN ANODES (Crowding Factor)

$$F = 1 + \frac{\rho}{\pi S R_H} ln 0.66N$$

Where

- F = Anode Interference or Crowding Factor
- ρ = resistivity in ohm-m
- R_H = resistance of single horizontal anode in ohms
- N = number of anodes
- S = distance between anodes in m

CALCULATE PIPE OR CABLE RESISTANCE FROM RESISTIVITY (Pouillet's Law)

$$R = \rho L/A$$

Where

R = resistance in ohms
ρ = resistivity in ohm-cm
A = cross-sectional area in cm^2
L = length in cm

WENNER SOIL RESISTIVITY

$$\rho = 2\pi\ AR$$

Where

ρ = soil resistivity in ohm-cm
A = distance between probes in cm
R = soil resistance in ohms {instrument reading}

OR

$$\rho = 191.5\ AR$$

Where

ρ = soil resistivity in ohm-cm
A = distance between probes in feet
R = soil resistance in ohms {instrument reading}

ATTENUATION

$$\alpha = \sqrt{rg}$$

Where

α = attenuation constant
r = longitudinal resistance of structure in ohms
g = conductance to earth in S

$$r' = R_L A_S$$

Where

r' = specific leakage resistance in ohm-m^2 (ohm-ft^2)
R_L = average total leakage resistance in ohms
A_S= total surface area in m^2 (ft^2)

$$R_G = \sqrt{\frac{r}{g}}$$

Where

R_G = characteristic resistance
r = longitudinal resistance of structure in ohms
g = conductance to earth in S

AC CURRENT DENSITY

$$i_{AC} = \frac{8V_{AC}}{\rho \pi d}$$

Where

i_{AC} = AC current density in A / m²
V_{AC} = AC Volts in V
ρ = soil resistivity in ohm-m
d = holiday diameter in m

TEMPERATURE CONVERSION

$$°C = \frac{5}{9}\,(°F - 32°)$$

$$°F = \frac{9}{5}\,(°C) + 32°$$

REFERENCE ELECTRODE TEMPERATURE CONVERSION

$$E = E^{o}_{25°C/SHE} + k_t(T - 25^{\circ}C)$$

Where

K_t = temperature coefficient in mV/(°C)
E_t = reference potential at temperature T in °C (SHE)
$E^{o}_{25°C/SHE}$ = reference potential at 25°C

INPUT IMPEDANCE MEASUREMENT CORRECTION

$$E_{true} = \frac{V_h(1-K)}{1 - K\frac{V_h}{V_l}}$$

Where

E_{true} = true potential in V
K = input resistance ratio $\frac{R_l}{Rh}$
R_l = lowest input resistance in ohms
R_h = highest input resistance in ohms
V_l = voltage measured with lowest input resistance in V
V_h = voltage measured with highest input resistance in V

LENGTH OF BARE STRUCTURE RECEIVING PROTECTION

$$L = 2d \tan 60°$$

Where

d = perpendicular distance between anode and structure
L = length of structure receiving protection

BARNES LAYER

$$R_{L2} = \frac{R_1 R_2}{(R_1 - R_2)}$$

Where

R_{L2} = resistance of layer 2 in ohms
R_1 = resistance measured to depth S_1 in ohms
R_2 = resistance measured to depth S_2 in ohms
$L_2 = S_2 - S_1$

KIRCHHOFF'S LAW

$$V_m = \frac{R_m}{R_t} \times E_t$$

Where

V_m = voltage drop across the voltmeter

R_m = voltmeter input resistance

R_t = total resistance

E_t = true potential

NERNST EQUATIONS

$$E_M = E_{M^o} + \frac{RT}{nF} ln \frac{\alpha^{M^{n+}}}{\alpha^{M^o}}$$

Where

E_M = metal potential

$E_M{}^o$ = metal potential at standard conditions

R = universal gas constant (J/mol-°K)

T = absolute temperature in kelvin

F = Faraday's Constant (96,500 coulombs)

$\alpha^{M^{n+}}$ = metal ion activity

α^{M^o} = metal activity

n = number of electrons transferred

CONVERSIONS

EMF	electromotive force – any voltage unit
E or e	any voltage unit
V	volts
mV	millivolts
µV	microvolts
I	any amperage unit
mA	milliamperes or milliamps
µA	microamperes or microamps
R or Ω	Resistance

1,000,000 volts	= 1 megavolt
1,000 volts	= 1 kilovolt
1.0 volt	= 1000 millivolts
0.100 volt	= 100 millivolts
0.010 volt	= 10 millivolts
0.001 volt	= 1 millivolt
0.000001 volt	= 1 microvolt
1,000,000 amperes	= 1 mega-ampere
1,000 amperes	= 1 kiloampere
1.0 ampere	= 1000 milliamperes
0.100 ampere	= 100 milliamperes
0.010 ampere	= 10 milliamperes
0.001 ampere	= 1 milliampere
0.000001 ampere	= 1 microampere
1,000,000 ohms	= 1 mega-ohm
1,000 ohms	= 1 kilo-ohm
1.0 ohms	= 1000 milliohms
0.100 ohm	= 100 milliohms
0.010 ohm	= 10 milliohms
0.001 ohm	= 1 milliohm
0.000001 ohm	= 1 micro-ohm
1 meter	= 100 cm
1 meter	= 1000 mm
1 inch	= 2.54 cm
1 foot	= 30.48 cm

U.S. Customary/Metric Conversion for Units of Measure Commonly Used in Corrosion-Related Publications

1 A/ft^2	= 10.76 A/m^2
1 acre	= 4,047 m^2 = 0.4047 ha
1 A·h/lb	= 2.205 A·h/kg
1 bbl (oil, U.S.)	= 159 L = 0.159 m^3
1 bpd (oil)	= 159 L/d = 0.159 m^3/d
1 Btu	= 1,055 J
1 Btu/ft^2	= 11,360 J/m^2
1 Btu/h	= 0.2931 W
1 Btu/h·ft^2	= 3.155 W/m^2 (K-factor)
1 Btu/h·ft^2·°F	= 5.678 W/m^2·K
1 Btu·in/h·ft^2·°F	= 0.1442 W/m·K
1 cfm	= 28.32 L/min = 0.02832 m^3/min = 40.78 m^3/d
1 cup	= 236.6 mL = 0.2366 L
1 cycle/s	= 1 Hz
1 ft	= 0.3048 m
1 ft^2	= 0.0929 m^2 = 929 cm^2
1 ft^3	= 0.02832 m^3 = 28.32 L
1 ft·lbf (energy)	= 1.356 J
1 ft·lbf (torque)	= 1.356 N·m
1 ft/s	= 0.3048 m/s
1 gal (Imp.)	= 4.546 L = 0.004546 m^3
1 gal (U.S.)	= 3.785 L = 0.003785 m^3
1 gal (U.S.)/min (gpm)	= 3.785 L/min = 0.2271 m^3/h
1 gal/bag (U.S.)	= 89 mL/kg (water/cement ratio)
1 grain	= 0.06480 g = 64.80 mg
1 grain/ft^3	= 2.288 g/m^3
1 grain/100 ft^3	= 22.88 mg/m^3
1 hp	= 0.7457 kW
1 microinch (µin)	= 0.0254 µm = 25.4 nm
1 in	= 0.0254 m = 2.54 cm = 25.4 mm
1 in^2	= 6.452 cm^2 = 645.2 mm^2
1 in^3	= 16.387 cm^3 = 0.01639 L
1 in·lbf (torque)	= 0.113 N·m
1 inHg	= 3.386 kPa

1 inH_2O	= 249.1 Pa
1 knot	= 0.5144 m/s
1 ksi	= 6.895 MPa
1 lb	= 453.6 g = 0.4536 kg
1 lbf/ft^2	= 47.88 Pa
1 lb/ft^3	= 16.02 kg/m^3
1 lb/100 gal (U.S.)	= 1.198 g/L
1 lb/1,000 bbl	= 2.853 mg/L
1 mA/in^2	= 0.155 mA/cm^2
1 mA/ft^2	= 10.76 mA/m^2
1 Mbpd (oil)	= 159 kL/d = 159 m^3/d
1 mile	= 1.609 km
1 square mile	= 2.590 km^2
1 mile (nautical)	= 1.852 km
1 mil	= 0.0254 mm = 25.4 µm
1 MMcfd	= 2.832 x 10^4 m^3/d
1 mph	= 1.609 km/h
1 mpy	= 0.0254 mm/y = 25.4 µm/y
1 oz	= 28.35 g
1 oz fluid (Imp.)	= 28.41 mL
1 oz fluid (U.S.)	= 29.57 mL
1 oz/ft^2	= 2.993 Pa
1 oz/gal (U.S.)	= 7.49 g/L
1 psi	= 0.006895 MPa = 6.895 kPa
1 qt (Imp.)	= 1.1365 L
1 qt (U.S.)	= 0.9464 L
1 tablespoon (tbs)	= 14.79 mL
1 teaspoon (tsp)	= 4.929 mL
1 ton (short)	= 907.2 kg
1 U.S. bag cement	= 42.63 kg (94 lb)
1 yd	= 0.9144 m
1 yd^2	= 0.8361 m^2
1 yd^3	= 0.7646 m^3

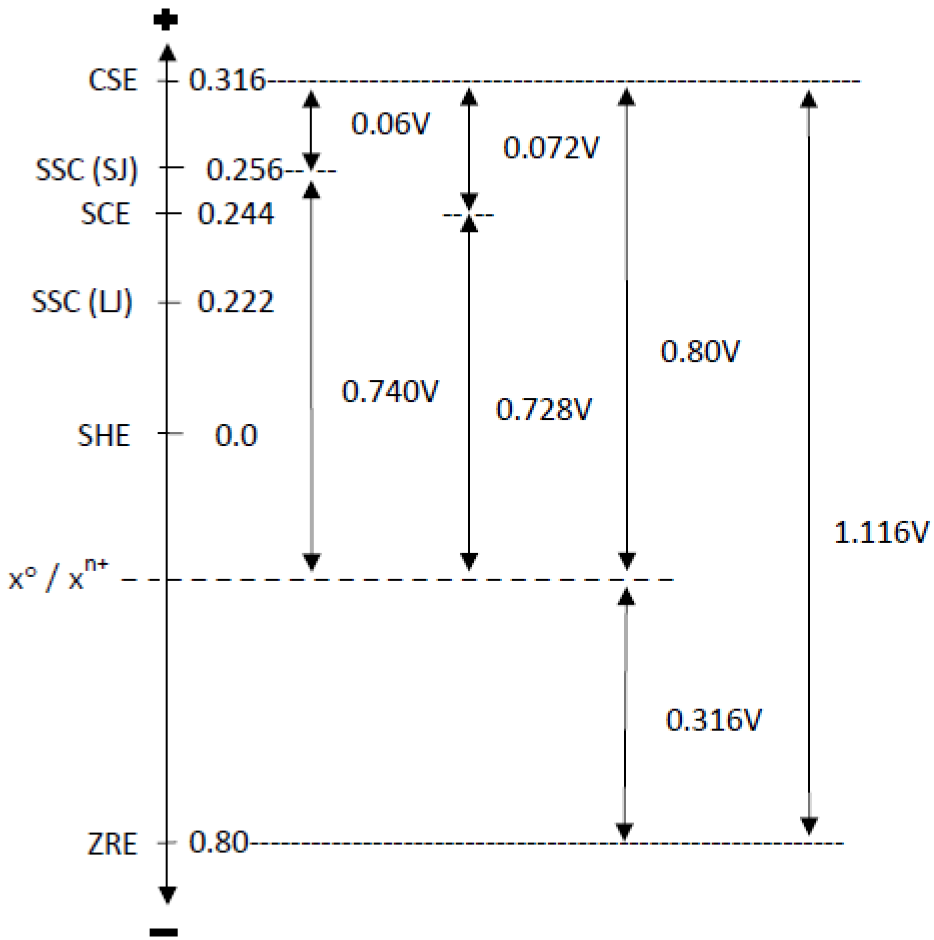
TABLES / SCALES

COMMON REFERENCE ELECTRODES AND THEIR POTENTIALS AT TEMPERATURE COEFFICIENTS

Reference Electrode	Electrolyte Solution	Potential @ 25°C ($V/_{SHE}$)	Temperature Co-efficient (mV/°C)
Cu / $CuSO_4$ (CSE)	Sat. $CuSO_4$	+0.316	0.9
Ag / AgCl (SJ) (SSC)	0.6M NaCl (3½%)	+0.256	−0.33
Ag / AgCl (LJ) (SSC)	Sat. KCl	+0.222	−0.70
Ag / AgCl (LJ) (SSC)	0.1N KCl	+0.288	−0.43
Sat. Calomel (SCE)	Sat KCl	+0.244	−0.70
Zn (ZRE)	Saline Solution	−0.79	---
Zn (ZRE)	Soil	−0.80	---

SJ – solid junction LJ – liquid junction

REFERENCE ELECTRODE CONVERSION SCALE



(SJ) = only solid silver chloride (AgCl) over the silver wire.

(LJ) = a silver wire surrounded by a concentrated solution of KCl.

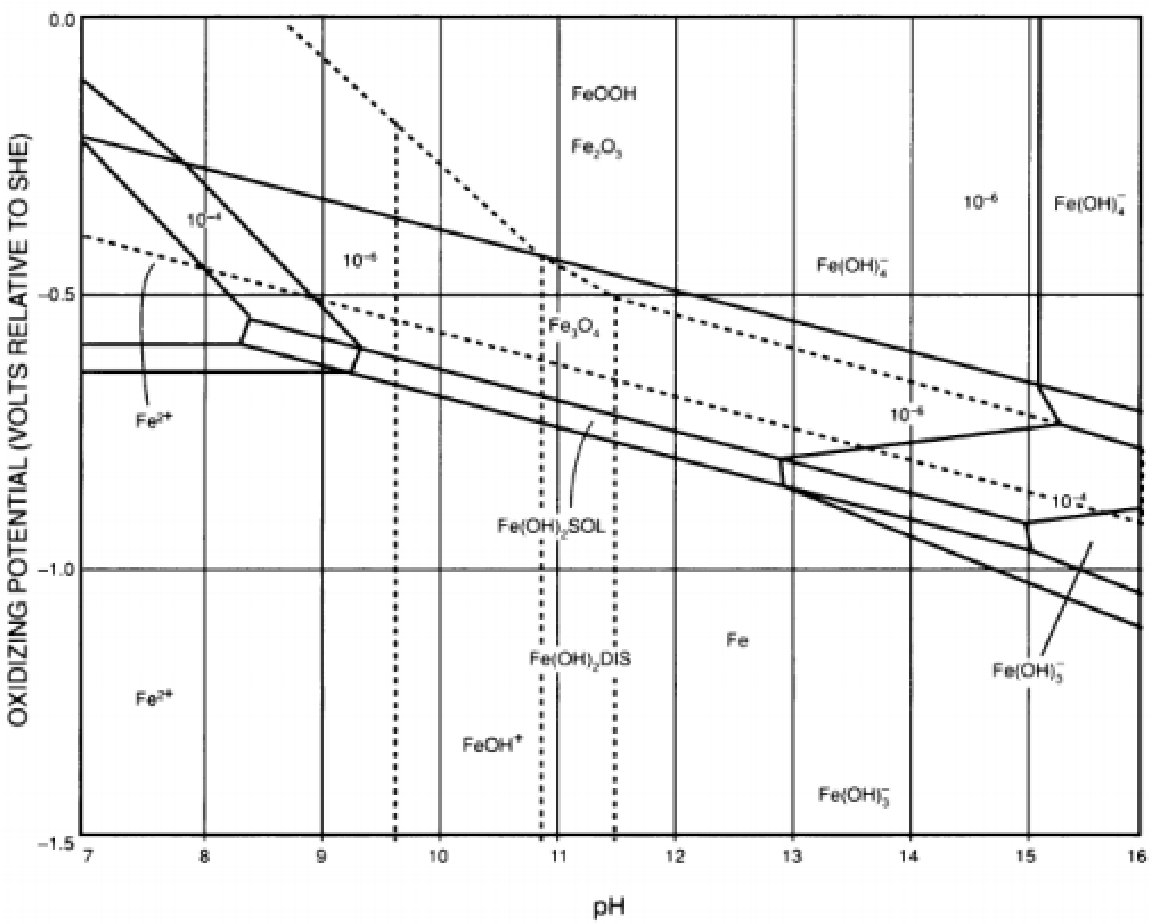
TYPICAL CONSUMPTION RATE AND CAPACITIES OF DIFFERENT ANODE MATERIALS IN SOILS OR FRESH WATERS

		Theoretical Consumption Rate		Theoretical Capacity		Typical Efficiency (1)
		kg / A-y	lb. / A-y	A-y / kg	A-y / lb.	%
Galvanic Anode Material	Magnesium	3.98	8.76	0.250	0.114	50
	Zinc	10.76	23.50	0.093	0.042	90
	Aluminum	2.94	6.49	0.340	0.155	85 - 95
Impressed Current Anode	Graphite / Carbon	0.1 to 1.0	0.22 to 2.2	10.1 to 1.0	4.5 to 0.45	
	High Silicon Iron	0.25 to 1.0	0.55 to 2.2	4.0 to 1.0	1.8 to 0.45	
	Steel	9.1	20	0.11	0.05	90

Note: Platinum clad and mixed metal oxide coated anodes are quantified by thickness of the surface film rather than by weight.

(1) Efficiency of galvanic anodes is dependent on the anode current density.

TYPICAL POTENTIAL-pH (POURBAIX) DIAGRAM IRON IN WATER AT 25°C



IONIC SPECIES ARE AT ACTIVITIES OF 10^{-4} AND 10^{-6}

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